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Applicant: PETER DANIEL HANSEN AND BULENT GOKSEL

Title: INTELLIGENT VALVE FLOW LINEARIZATION

Enclosed are the following papers, including those required to receive a filing date under 37 CFR 1.53(b):

	Pages
Specification	14
Claims	5
Abstract	1
Declaration	2
Drawing(s)	6

Enclosures:
— Assignment cover sheet and an assignment, 2 pages, and a separate $40 fee.
— Postcard.

Basic filing fee	$690
Total claims in excess of 20 times $18	$126
Independent claims in excess of 3 times $78	$0
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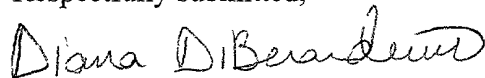Kindly acknowledge receipt of this application by returning the enclosed postcard.

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APPLICATION

FOR

UNITED STATES LETTERS PATENT

TITLE: INTELLIGENT VALVE FLOW LINEARIZATION

APPLICANT: PETER DANIEL HANSEN AND BULENT GOKSEL

INTELLIGENT VALVE FLOW LINEARIZATION

5

Technical Field

This invention relates to controlling flow through a valve using a valve positioner.

10

Background

A valve positioner system controls the position of a valve in response to a setpoint signal. For example, in a chemical mixing process, a valve positioner system may be used to regulate flow to control a concentration of a particular chemical in the mixing process. A chemical mixing process controller monitors the concentrations of all chemicals in the mix and provides setpoint signals to various valve positioners which control the flow of the chemicals.

A valve positioner system controls position of the valve by comparing a measured position with a setpoint or target position and changing an output used to control the position of the valve accordingly. The valve positioner system typically includes a current-to-pressure (i/p) transducer that receives a variable electrical input signal and provides a pneumatic output signal. The valve positioner employs the i/p transducer in a feedback loop that includes a pneumatic relay, a valve actuator, a valve having a valve stem attached to a valve flow modulating member, a positioner feedback linkage, a position sensor, and a microprocessor.

The microprocessor receives the setpoint signal and produces the input signal for the i/p transducer. The valve actuator responds to the pressure change produced by the pneumatic relay by driving the valve stem to control the degree to which the valve flow modulating member is open. The positioner feedback linkage transmits the position of the valve stem to the position sensor, which provides a signal indicative of the position to the microprocessor. The microprocessor then adjusts the signal supplied to the i/p transducer so as to move the valve flow modulating member to the position indicated by the setpoint, or to maintain the position of the valve flow modulating member at the setpoint.

Summary

In one general aspect, a flow rate of a fluid through a valve flow modulating member controlled by a position of a valve stem is controlled by setting a target flow rate. A target valve stem position is determined based on the target flow rate. The valve stem position is adjusted until a position of the valve stem matches the target valve stem position.

Embodiments may include one or more of the following features. For example, determining the target valve stem position may include calculating a flow area of the valve flow modulating member and estimating a pressure coefficient. The flow area of the valve flow modulating member may be calculated using the measured flow rate and the estimated pressure coefficient.

The target valve stem position may be determined by determining a valve stem position corresponding to the calculated flow area. Determining the valve stem position may include using a predetermined relationship between the valve stem position and the flow area.

Additionally, calculating the flow area of the valve flow modulating member may include modelling flow rate through the valve flow modulating member relative to the flow area of the valve flow modulating member. In this way, a relationship between a pressure function, the flow area of the valve flow modulating member, and the flow rate through the valve flow modulating member may be determined. The pressure function is based on estimates of the fluid pressure upstream and downstream from the valve flow modulating member.

The fluid may be in a gaseous state. For such a fluid, the modelling may assume that an internal energy of the fluid is constant across the valve flow modulating member. Furthermore, the modelling may include estimating or determining from process data the pressure of the fluid upstream from the valve flow modulating member and the pressure of the fluid downstream from the valve flow modulating member. The pressure coefficient may be based on a ratio of the difference between the upstream pressure squared and the downstream pressure squared when the valve flow modulating member is fully open to that difference when it is fully closed.

The fluid also may be in a liquid state. In this case, the modelling may assume that a density of the fluid remains substantially constant as the fluid travels across

the valve flow modulating member. The modelling may include estimating or determining from process data the pressure of fluid upstream from the valve flow modulating member and a pressure of the fluid downstream from the valve flow

5   modulating member. The pressure coefficient may be based on a ratio of the difference in the upstream pressure and the downstream pressure when the valve flow modulating member is fully open to that difference when it is fully closed.

In another general aspect, a valve positioner system controls a flow rate of a fluid through a valve flow modulating member that is controlled by a position of a valve

10   stem. To this end, the system includes a valve positioner coupled to the valve stem and a feed-forward flow controller.

The valve positioner compares a measured position of the valve stem with a target position and adjusts the valve stem to drive the measured position to the target position. The target position can be calculated to achieve a target flow through the valve.

15   Also, an estimate of the actual flow can be back calculated from the measured valve position.

Embodiments may include one or more of the following features. For example, the feed-forward flow controller may be configured to determine a pressure coefficient that is based on one or more estimates of the pressure of the fluid relative to

20   the valve flow modulating member.

The feed-forward flow controller may be configured to back calculate a flow area of the valve flow modulating member that corresponds to the measured valve stem position. The feed-forward flow controller may also be configured to back calculate a flow rate based on the back calculated flow area and the pressure coefficient.

25   The feed-forward flow controller may be configured to calculate a target flow area based on a target flow rate and the pressure coefficient.

The target valve stem position may be calculated based on the calculated feed-forward flow area. Calculating the target valve stem position may include using a predetermined relationship between valve stem position and a flow area of the valve flow

30   modulating member which depends on the geometry of the valve flow modulating member.

Back calculating the flow area may include using a predetermined relationship between valve stem position and a flow area of the valve flow modulating member.

A purpose of the target flow determination is to linearize the process seen by a
5   feed-back flow controller so that the feed-back flow controller tuning remains near optimal over the operating range of the process.

Other features and advantages will be apparent from the following description, including the drawings, and from the claims.

10   Drawing Description

Fig. 1 is a block diagram of a valve positioner system that controls a position of a valve stem and a corresponding valve flow modulating member, and determines the position target from a flow target.

Fig. 2 is a drawing of a valve that includes a valve flow modulating member.

15   Fig. 3 is a block diagram of a valve positioner implemented in the valve positioner system of Fig. 1.

Fig. 4 is a flow chart of a procedure for calculating a target valve stem position and a fluid flow rate that corresponds to a measured valve stem position.

Fig. 5 is a graph comparing measured gas flow rate through an orifice with a
20   gas flow rate that is calculated using isothermal approximations.

Fig. 6 is a graph showing a relationship between fluid flow rate and flow area for a pressure coefficient β with a value of 1/3 and 1.

Detailed Description

25   Referring to Fig. 1, a valve positioner system 100 includes a valve flow modulating member 105 that adjusts a flow rate F of a fluid through a fluid flow line defined by a process pipe or duct 107. A generalized example of the valve flow modulating member 105 and the process pipe 107 is shown in Figs. 2. For example, the valve flow modulating member 105 may be of the globe valve type or of the butterfly
30   valve type. The valve flow modulating member 105 is designed to yield a predetermined relationship between valve position and the fluid flow rate F.

4

The valve flow modulating member 105 is positioned by a piston or diaphragm controlled by a pneumatic actuator or an electric actuator 110. Force or torque generated by the actuator 110 drives a valve stem 115 that is coupled to the valve

5 flow modulating member 105. A position of the valve stem 115 is indicated by variable X. A change in the position X of the valve stem 115 causes a corresponding change in a valve flow modulating member area through which fluid flows. The valve flow modulating member 105 changes the flow rate F of the fluid by adjusting the valve flow modulating member area. Alternatively, the valve flow modulating member can be

10 opened or closed by other means such as an electric motor or hydraulic actuator.

In Fig. 2, the valve stem 115 causes the valve flow modulating member 105 to move between a "closed" position C (in which the flow path is fully closed) and an "opened" position B (in which the flow path is fully opened). When the valve flow modulating member 105 is in the opened position B, flow area A is at a maximum A_{max}.

15 A valve positioner 120 compares a valve stem position setpoint x_f to the actual valve stem position X, measured by a position sensor 125, and adjusts a pressure p_x, in the pneumatic actuator 110 until the valve stem position X matches the setpoint x_f. Changes in the pressure p_x produce corresponding changes in the position X of the valve stem 115. A feedback linkage is used to close the loop between the valve stem 115 and

20 the valve positioner 120.

Fluid is supplied through the process pipe 107 using a pump or compressor 140. Fluid supplied from the pump or compressor 140 may have a load 145 upstream of the valve flow modulating member 105 and a load 150 downstream of the valve flow modulating member 105. Upstream of the valve flow modulating member 105, fluid

25 pressure may be represented as p_1. Downstream of the valve flow modulating member 105, fluid pressure may be represented as p_2. The pressure differential across the valve flow modulating member 105 is therefore $p_1 - p_2$ and the squared pressure differential is $p_1{}^2 - p_2{}^2$. Pressure caused by the compressor or pump 140 to the upstream load 145 is p_s and return pressure to the compressor or pump 140 after the downstream load 150 is p_d.

30 For simplicity and ease of performing calculations, each variable -- valve stem position X, fluid flow rate F, and flow area A -- is normalized by its respective maximum value X_{max}, F_{max}, and A_{max}. Throughout this discussion, all variables are normalized, and

are thus given in dimensionless units. Therefore, a normalized valve stem position, x equals X/X_{max}; a normalized flow rate v equals F/F_{max}; and a normalized area y equals A/A_{max}. Normalized variables range from 0 to 1. Moreover, the flow rate F may be a

5   volumetric flow rate (that is, given in units of volume/time) or it may be a mass flow rate (that is, given in units of mass/time). Units for the flow rate are generally selected based on the state of the fluid. For example, for gases, a mass flow rate is used, whereas for liquids, either the mass flow rate or the volumetric flow rate may be used since density changes are assumed negligible.

10   An open-loop flow control correction makes the fluid flow rate approximately equal to its setpoint or target value. This feed-forward flow control correction may be implemented in a feed-forward flow controller 155, an analog output block, or the valve positioner 120. For the purposes of illustration, the feed-forward flow control correction is drawn as a separate component, that is, the feed-forward flow controller 155, in the

15   valve positioner system 100.

          The feed-forward flow controller 155 determines a normalized target valve stem position x_f based on the target fluid flow rate v_f and provides this target position x_f to the valve positioner 120. The target fluid flow rate may result from an upstream controller or it may be manually modulated or fixed. The valve positioner 120 compares

20   the valve stem target position x_f to a normalized valve stem position x_b generated from the position x measured by the position sensor 125, and adjusts the pressure p_x in the pneumatic actuator 110 until the valve stem position x matches the target valve stem position x_f.

          Fig. 3 provides a simplified block diagram of the valve positioner 120. A

25   position transducer 300 receives feedback from the position sensor 125 coupled to the valve stem 115 and produces a signal indicative of the valve stem position. This feedback enables the valve positioner 120 and the feed-forward flow controller 155 to adjust the fluid flow rate.

          The target valve stem position x_f and the measured valve stem position x are

30   supplied to a valve position controller 305 which may be implemented in a microprocessor. In many implementations, the target position signal takes the form of a digital signal that indicates a desired position for the valve stem. The target position signal also may be an analog signal indicative of a desired valve stem position.

The valve position controller 305 uses proportional, integral, and derivative control (for example, PID control) to generate a control signal u that is dependent on the target valve stem position x_f and the measured valve stem position x. A current-to-

5   pressure (i/p) transducer 310 converts the valve position controller output signal u into a pneumatic signal. The i/p transducer 310 is used in conjunction with a pneumatic preamplifier 315 which may provide immunity to fluctuations in the supply air pressure. Output of the preamplifier 315 is fed to a pneumatic relay 320, which may increase the magnitude of the output pressure p_x in addition to the flow rate of air supplied to the

10 pneumatic actuator 110. Pneumatic actuator pressure is fed back to the relay 320. The i/p transducer 310, preamplifier 315, and relay 320 receive supply air that may be regulated at, for example, 20-90 psig. Pneumatic pressure p_x from an output of the relay 320 is supplied to the pneumatic actuator 110. If a double-acting pneumatic actuator 110 is used, pressure is required on both sides of the pneumatic actuator for it to operate.

15 Therefore, the pneumatic relay 320 has two outputs that feed the double-acting pneumatic actuator 110. For a single-acting pneumatic actuator 110, a spring supplies the required return force.

Fig. 4 provides a block diagram of the feed-forward flow controller 155. As noted above, the feed-forward flow controller 155 may be implemented within the valve

20 positioner 120, and more specifically, within the valve position controller 305.

In general, the feed-forward flow controller 155 relates the target valve stem position x_f to the target flow rate v_f to provide a feed-forward open-loop correction to the valve stem position x. To do this, the feed-forward controller 155 calculates a target normalized valve flow area y_f from the target flow rate v_f and a user configured tuning

25 parameter or pressure coefficient β. Then, using a predetermined relationship, f, the feed-forward controller 155 determines a target valve stem position x_f that corresponds to the calculated target flow area y_f. The predetermined relationship f is provided by the manufacturer of the valve assembly.

One example of the relationship f written in its inverse form is:

$$y = f^{-1}(x) = \left(\frac{A_{max}}{A_{min}}\right)^{x-1},$$

(1)

7

where A_{max} and A_{min} are, respectively, maximum and minimum flow areas. This relationship is used for equal percentage valves. When a linear valve is used, the relationship f may be expressed as a linear relationship. That is, $x=f(y)=y$.

5   The relationship between the flow rate v_f, the target flow area y_f, and the coefficient β is determined by modelling fluid flow rate through the process pipe 107 and valve flow modulating member 105. For an ideal gas flowing through a pipe, the change in pressure $(-dp)$ per unit length of pipe (dl), that is, $-dp/dl$, may be estimated by the equation:

10

$$-\frac{dp}{dl} = \frac{4 f_p}{d} \cdot \frac{\rho \cdot V^2}{2 g_c}, \qquad\qquad (2)$$

where f_p is a constant friction factor, d is the diameter of the pipe approximated to be circular in shape, ρ is an average density of the gas, V is the velocity of the gas, and g_c is the gravitational constant. For a gas, the velocity V may be written in terms of the mass flow rate W using $V = W/\rho A$. Therefore, Eqn. 2 becomes:

$$-\frac{dp}{dl} = \frac{4 f_p}{d} \cdot \frac{W^2}{\rho \cdot A^2 \cdot 2 g_c}. \qquad\qquad (3)$$

For an ideal gas, $p/\rho = RT$, where p is the absolute pressure, ρ is the density of the gas, T is the absolute temperature, and R is the universal gas constant. Therefore,

20 using this substitution, Eqn. 3 becomes:

$$-\frac{dp}{dl} = \frac{4 f_p}{d} \cdot \frac{W^2 \cdot RT}{p \cdot A^2 \cdot 2 g_c}. \qquad\qquad (4)$$

8

Assuming enthalpy (and internal energy) remain constant along the length L of the pipe, the temperature T remains constant, and Eqn. 4 may be integrated:

$$-\int_{P_1}^{P_2} p \, dp = \frac{4f_p}{d} \frac{W^2 \cdot RT}{A^2 \cdot 2g_c} \int_0^L dl.$$ (5)

5

Integrating Eqn. 5 gives the relationship between the difference in pressure squared across the pipe relative to the mass flow rate W and orifice area A:

$$p_1^2 - p_2^2 = \frac{4f_p L}{d} \frac{RT}{g_c} \frac{W^2}{A^2}.$$ (6)

10 Solving for W/A, Eqn. 6 becomes:

$$\frac{W}{A} = \sqrt{\frac{d}{4f_p L}} \sqrt{\frac{g_c}{RT}} \sqrt{p_1^2 - p_2^2}.$$ (7)

A similar equation can be applied to flow through a sharp edged orifice using a fixed coefficient $C_D = 0.6$:

15

$$\frac{W}{A} = 0.6 \sqrt{\frac{g_c}{RT}} \sqrt{p_1^2 - p_2^2}.$$ (8)

    Referring also to graph 500 in Fig. 5, results from Eqn. 8 may be compared with experimental results 505 obtained by A. H. Shapiro in Chapter 4, pages 99-100 of "The Dynamics and Thermodynamics of Compressible Fluid Flow", which is

20 incorporated herein by reference. Shapiro defines a discharge coefficient as the ratio of

9

the actual flow rate F through an orifice to the flow rate calculated from isentropic laws for the initial p_1 and the final p_2 pressures of the orifice (labelled isentropic flow rate). The ratio is not constant because there is jet contraction in the fluid stream following the

5 orifice that is affected by the downstream pressure propagating upstream in the low velocity eddies. Typically, design procedures are based on the use of the isentropic flow formulas modified by empirically determined variable coefficients such as the coefficient of discharge.

The ratio between the flow rate in Eqn. 8 which is determined using constant-

10 temperature (that is, isothermal) flow formulas, and the isentropic flow rate is shown as open-circled results 510 in graph 500. Results 510 are in good agreement with experimental values 505.

Therefore, Eqn. 8 is used to determine, for an ideal gas, the relationship between the target flow rate v_f and the target area y_f that will be used in the feed-forward

15 flow controller 155. Rewriting A in terms of the maximum area A_{max} and the area y, solving for $p_1^2 - p_2^2$, and setting a parameter K_V equal to $g_c C_D^2 A_{max}^2 / RT$ gives:

$$\delta(p_v^2) = p_1^2 - p_2^2 = \frac{1}{K_v} \frac{W^2}{y^2}. \tag{9}$$

The derivation of the relationship used by the feed-forward flow controller

20 between the fluid flow rate through an orifice and the orifice area will be developed first with respect to liquids and then with respect to gases. For liquids, the commonly-used relationship between the pressure differential across an orifice, the liquid flow rate, and orifice area is found by assuming that the density of the liquid remains constant across the orifice. This relationship is written:

25

$$\delta p_v = p_1 - p_2 = \frac{1}{K_V} \frac{F^2}{y^2}. \tag{10}$$

A pressure differential (also called a pressure functional) from the pump or compressor 140 to and from the valve flow modulating member 105 in the fluid line may be written as δp_L. Upstream from the orifice, the pressure functional is $p_s - p_1$ and

5   downstream from the orifice, the pressure functional is $p_2 - p_d$. The sum of these pressure functionals depends on the loads 145 and 150 in the fluid line and is given by the expression:

$$\delta p_L = \frac{F^2}{K_L},\qquad (11)$$

10   where K_L is a constant that depends on the load values 145 and 150. Note that the normalized area y does not enter into Eqn. 11 because the pressure functionals are measured outside the valve flow modulating member.

A total pressure functional, δp, between the supply and drain is $p_s - p_d$ and is found by adding Eqns. 10 and 11:

15

$$\delta p = \delta p_v + \delta p_L = F^2 \left(\frac{1}{K_v y^2} + \frac{1}{K_L} \right),\qquad (12)$$

or

$$\delta p = F_{max}^2 \left(\frac{1}{K_v} + \frac{1}{K_L} \right).\qquad (13)$$

The fluid flow rate v is:

20

11

$$v^2 = \frac{F^2}{F_{max}^2} = \frac{\dfrac{1}{K_v} + \dfrac{1}{K_L}}{\dfrac{1}{K_v y^2} + \dfrac{1}{K_L}}, \qquad (14)$$

where F_{max} is the maximum flow rate corresponding to a maximum area $y_{max} = 1$.
Because the pressure coefficient β need not be an exactly calculated quantity to obtain a
substantial improvement in the behavior of the flow loop, it may be estimated using
maximum flow conditions, namely $v=y=1$. If the coefficient β is defined as:

$$\beta = \frac{\delta p_V (v = y = 1)}{\delta p} = \frac{\dfrac{1}{K_V}}{\dfrac{1}{K_V} + \dfrac{1}{K_L}}, \qquad (15)$$

then Eqn. 14 becomes:

$$\frac{1}{v^2} = (1 - \beta) + \frac{\beta}{y^2}. \qquad (16)$$

For gases, the flow derivation follows much the same form as it does for
liquids. First, a squared absolute pressure differential (or absolute pressure functional)
across the fluid line, equals $p_s^2 - p_1^2$ for the upstream fluid line and $p_2^2 - p_d^2$ for the
downstream fluid line, and their sum is generally written as:

$$\delta(p_L^2) = \frac{W^2}{K_L}. \qquad (17)$$

The squared absolute pressure functional between the supply and drain is $\delta(p^2)$, the sum of $\delta(p_L^2)$ from Eqn. 17 and $\delta(p_V^2)$ from Eqn. 9:

$$\delta(p^2) = W^2\left(\frac{1}{K_V y^2} + \frac{1}{K_L}\right).$$ (18)

5

Writing the normalized flow rate v as:

$$v^2 = \frac{W^2}{W_{max}^2} = \frac{\dfrac{1}{K_V} + \dfrac{1}{K_L}}{\dfrac{1}{K_V y^2} + \dfrac{1}{K_L}},$$ (19)

and defining the coefficient β to be:

10

$$\beta = \frac{\delta(p_v^2(v=y=1))}{\delta(p^2)} = \frac{\dfrac{1}{K_V}}{\dfrac{1}{K_V} + \dfrac{1}{K_L}},$$ (20)

gives the relationship between the fluid flow rate v and the area y:

$$\frac{1}{v^2} = (1-\beta) + \frac{\beta}{y^2}.$$ (21)

Therefore, using the isothermal flow equations, gases may easily be treated like liquids
15   using Eqns. 16 and 21.

13

Referring again to Fig. 4, the feed-forward flow controller 155 receives a target normalized flow rate v_f 400 in addition to the predetermined pressure coefficient β 405 to calculate (step 450) a target normalized flow area y_f 410. Then, using the

5 predetermined function f, the target normalized valve stem position x_f 415 is calculated (step 455). This target valve stem position x_f 415 is fed into the valve positioner 120 which then adjusts the pressure p_x in the pneumatic actuator 110 to change the valve stem position and cause a change in the flow area and therefore a change in the fluid flow rate. Feedback from the position sensor 125 is provided to the valve positioner which then

10 sends a measured normalized valve stem position x_b 420 to the feed-forward flow controller 155.

The feed-forward flow controller 155 then performs a back calculation to provide a flow feedback signal to an upstream controller. First, the feed-forward flow controller 155 uses a function f^{-1} that is the inverse of the manufacturer supplied function

15 f to calculate (step 460) a normalized flow area y_b 425 that corresponds to the measured valve stem position x_b 420. Using the corresponding flow area y_b 425, the feed-forward flow controller 155 performs an inverse calculation (step 465) of the calculation 450 to determine a normalized flow rate v_b 430 that corresponds to the measured valve stem position x_b 420. The normalized flow rate v_b 430 may be fed back to an upstream

20 controller which then adjusts its output, v_f, typically using PID feedback control. The flow feedback signal is used to help initialize the upstream controller and to avoid integrator windup.

A graph 600 of the flow rate v versus the flow area y is shown in Fig. 6. Values of the flow area y ranged from 0 to 1. The coefficient β was set to 1/3 in this

25 example, to provide maximum power to a load when the valve flow modulating member is fully open. The relationship between the valve stem position x and the flow area y is assumed linear for the purposes of illustration. The nonlinear flow rate v vs. area y is graphed in the solid line 605, for β=1/3. The dashed line 610 represents a linear relationship which is achieved when β=1 (that is, all of the pressure drop is across the

30 valve).

Other embodiments are within the scope of the following claims.

What is claimed is:

14

1   1.   An open loop method of controlling flow rate of a fluid through a
2 valve flow modulating member that is controlled by a position of a valve stem, the
3 method comprising:
4   setting a target flow rate;
5   determining a target valve stem position based on the target flow rate; and
6   adjusting the valve stem position until a position of the valve stem matches
7 the target valve stem position.

1   2.   The method of claim 1, wherein determining the target valve stem
2 position comprises:
3   determining a pressure coefficient;
4   calculating a flow area of the valve flow modulating member; and
5   determining a valve stem position corresponding to the calculated flow area.

1   3.   The method of claim 2, wherein calculating the flow area of the valve
2 flow modulating member comprises using the measured flow rate and the determined
3 pressure coefficient.

1   4.   The method of claim 2, wherein determining the valve stem position
2 comprises using a predetermined relationship between the valve stem position and the
3 flow area.

1   5.   The method of claim 2, wherein calculating the flow area of the valve
2 flow modulating member comprises modelling flow rate through the valve flow
3 modulating member to determine a relationship between a function of fluid pressure
4 upstream and downstream from the valve flow modulating member, the flow area of the
5 valve flow modulating member, and the flow rate through the valve flow modulating
6 member.

1   6.   The method of claim 5, wherein the modelling assumes that an internal
2 energy of the fluid is constant across the valve flow modulating member.

1   7.   The method of claim 5, wherein the modelling assumes that a density

2 of the fluid remains substantially constant across the valve flow modulating member.

1   8.   The method of claim 2, wherein the fluid is in a gaseous state.

1   9.   The method of claim 8, wherein calculating the flow area of the valve

2 flow modulating member comprises estimating a pressure of the fluid upstream from the

3 valve flow modulating member and a pressure of the fluid downstream from the valve

4 flow modulating member.

1   10.   The method of claim 8, wherein the pressure coefficient includes a

2 squared pressure difference ratio.

1   11.   The method of claim 8, wherein the pressure coefficient is estimated

2 using maximum and minimum flow conditions.

1   12.   The method of claim 2, wherein the fluid is in a liquid state.

1   13.   The method of claim 12, wherein the pressure coefficient is estimated

2 using maximum and minimum flow conditions.

1   14.   The method of claim 12, wherein calculating the flow area of the valve

2 flow modulating member comprises estimating a pressure of fluid upstream from the

3 valve flow modulating member and a pressure of the fluid downstream from the valve

4 flow modulating member.

1   15.   The method of claim 12, wherein the pressure coefficient includes a

2 ratio of the difference in the upstream pressure and the downstream pressure when the

3 valve flow modulating member is fully open to the difference in the upstream pressure

4 and the downstream pressure when the valve flow modulating member is fully closed.

1 16.   A valve positioner system that controls a flow rate of a fluid through a

2 valve flow modulating member that is controlled by a position of a valve stem, the

3 system comprising:

4   a valve positioner coupled to the valve stem and configured to measure a

5 position of the valve stem;

6   a feed-forward flow controller configured to:

7   receive the measured valve stem position from the valve positioner,

8   receive the target flow rate from the flow controller, and

9   calculate a target valve stem position based on the target flow rate;

10   wherein the valve positioner adjusts the valve stem position until a position of

11 the valve stem matches the target valve stem position.

1 17.   The system of claim 16, wherein the feed-forward flow controller is

2 configured to determine a pressure coefficient that is based on one or more estimates of

3 the pressure of the fluid relative to the valve flow modulating member.

1 18.   The system of claim 17, wherein the feed-forward flow controller is

2 configured to:

3   calculate a flow area of the valve flow modulating member that corresponds to

4 the measured valve stem position; and

5   calculate a flow rate based on the calculated flow area and the pressure

6 coefficient.

1 19.   The system of claim 18, wherein the target valve stem position is

2 calculated based on the calculated flow area.

1 20.   The system of claim 19, wherein calculating the target valve stem

2 position comprises using a predetermined relationship between valve stem position and a

3 flow area of the valve flow modulating member.

1   21.   The system of claim 18, wherein calculating the flow area comprises

2 using a predetermined relationship between valve stem position and a flow area of the

3 valve flow modulating member.

1   22.   The system of claim 18, wherein calculating the flow area of the valve

2 flow modulating member comprises modelling flow rate through the valve flow

3 modulating member to determine a relationship between a function of fluid pressure

4 upstream and downstream from the valve flow modulating member, the flow area of the

5 valve flow modulating member, and the flow rate through the valve flow modulating

6 member.

1   23.   The system of claim 22, wherein the fluid is in a gaseous state.

1   24.   The system of claim 23, wherein the modelling assumes that an

2 internal energy of the fluid is constant across the valve flow modulating member.

1   25.   The system of claim 22, wherein the fluid is in a liquid state.

1   26.   The system of claim 25, wherein the modelling assumes that a density

2 of the fluid remains substantially constant across the valve flow modulating member.

1   27.   A valve positioner system that controls a flow rate of a fluid through a

2 valve flow modulating member that is controlled by a position of a valve stem, the

3 system comprising:

4   a valve positioner coupled to the valve stem and configured to measure a

5 position of the valve stem; and

6   a feed-forward flow controller configured to:

7   receive the measured valve stem position from the valve positioner,

8   receive the target flow rate from the flow controller,

9   receive a pressure coefficient,

10   calculate a first flow area based on the target flow rate and the pressure

11 coefficient;

12

12   calculate a second flow area that corresponds to the measured valve

13 stem position,

14   calculate a flow rate based on the calculated second flow area and the

15 pressure coefficient,

16   calculate a target valve stem position based on the calculated first flow

17 area;

18   wherein the valve positioner adjusts the valve stem position until a position of

19 the valve stem matches the target valve stem position.

INTELLIGENT VALVE FLOW LINEARIZATION

Abstract

A feed-forward flow controller is designed to calculate a target valve position from a target flow. Correction is made for liquid or gas pressure drop across the valve and for the valve flow modulating member geometry. This feed-forward action may also be used to linearize a feed-back flow control loop.
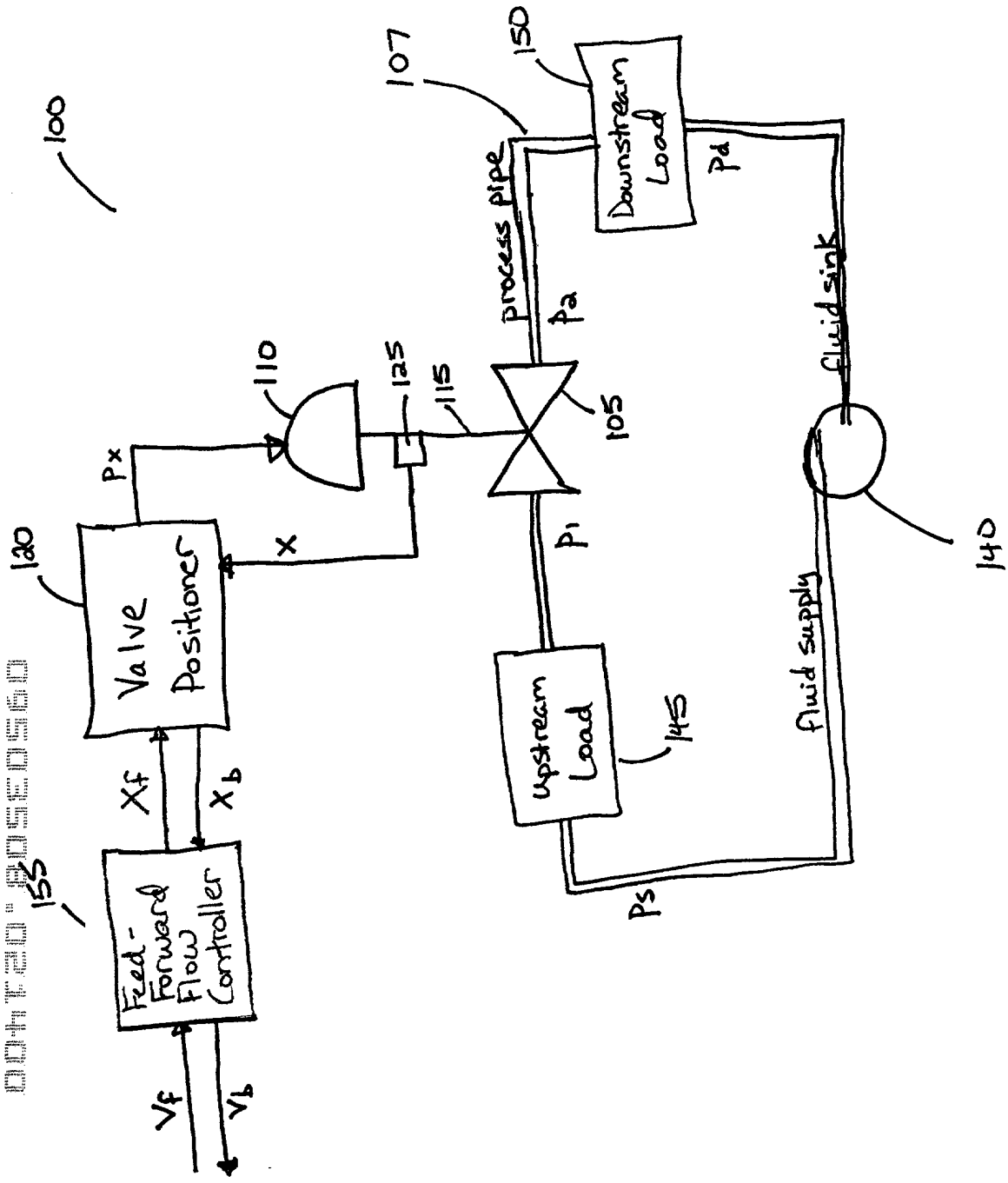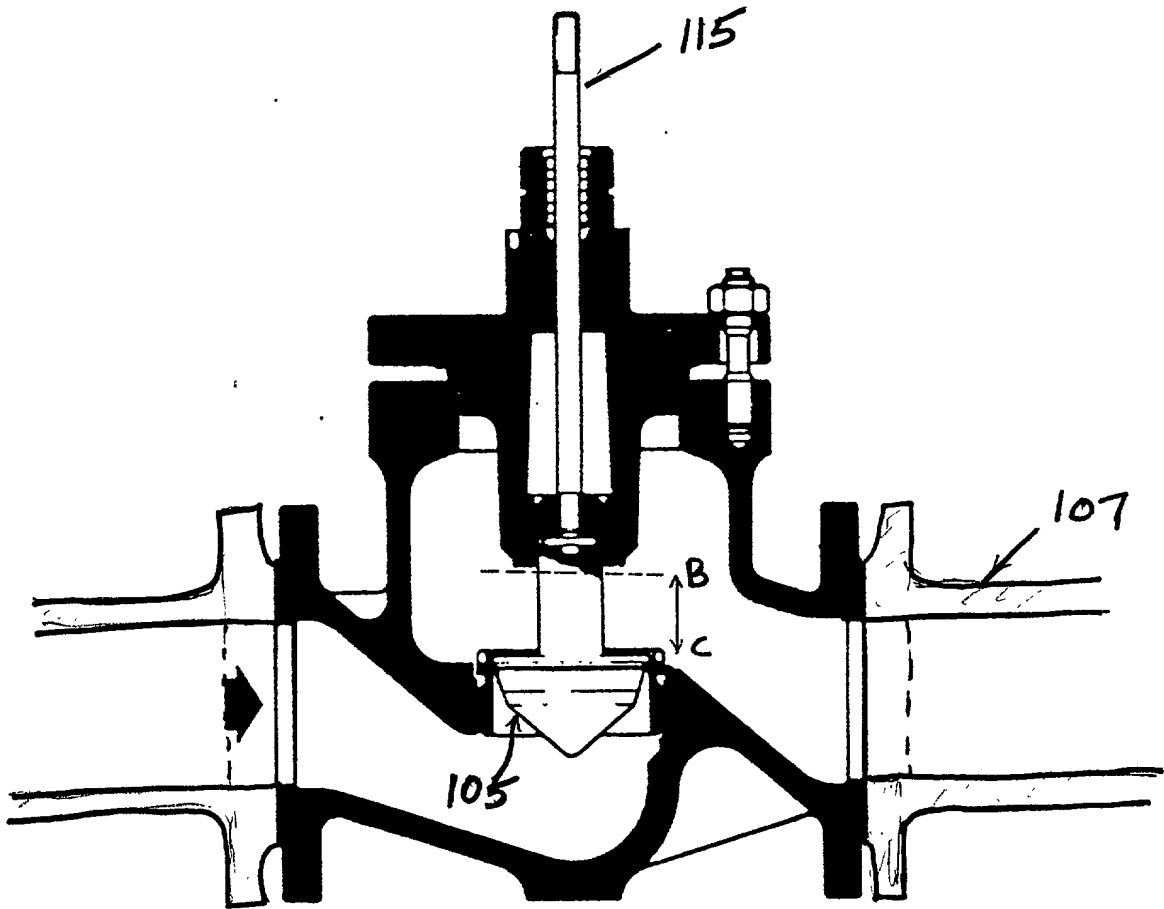
40019942.doc

Fig. 1

115

107

B

C

105

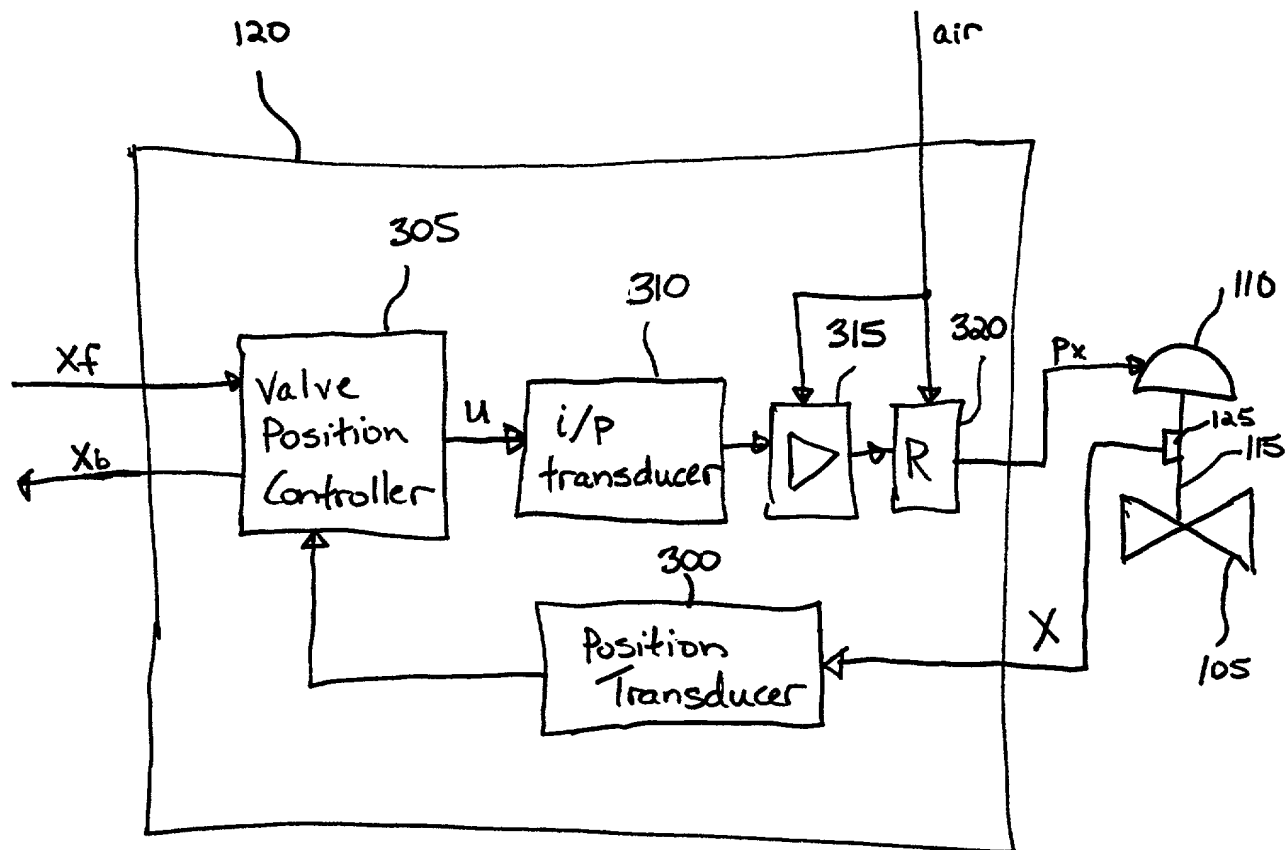C: flowpath fully
closed

B: flow path
fully open

Fig. 2

120

air

305

310

315   320

Xf

Valve
Position
Controller

U

i/P
transducer

▷   R

Px

110

125

115

Xb

300

Position
Transducer

X

105

Fig. 3

Valve Positioner — 120

$x_f = f(y_f)$

$y_b = f^{-1}(x_b)$

$$y_f^2 = \frac{\beta v_f^2}{1 - v_f^2(1-\beta)}$$

$$v_b^2 = \frac{y_b^2}{\beta + y_b^2(1-\beta)}$$

155

455

415   x_f x_b 420

450   y_f 410 y_b 425   460

v_f 400   405 β v_b 430   465
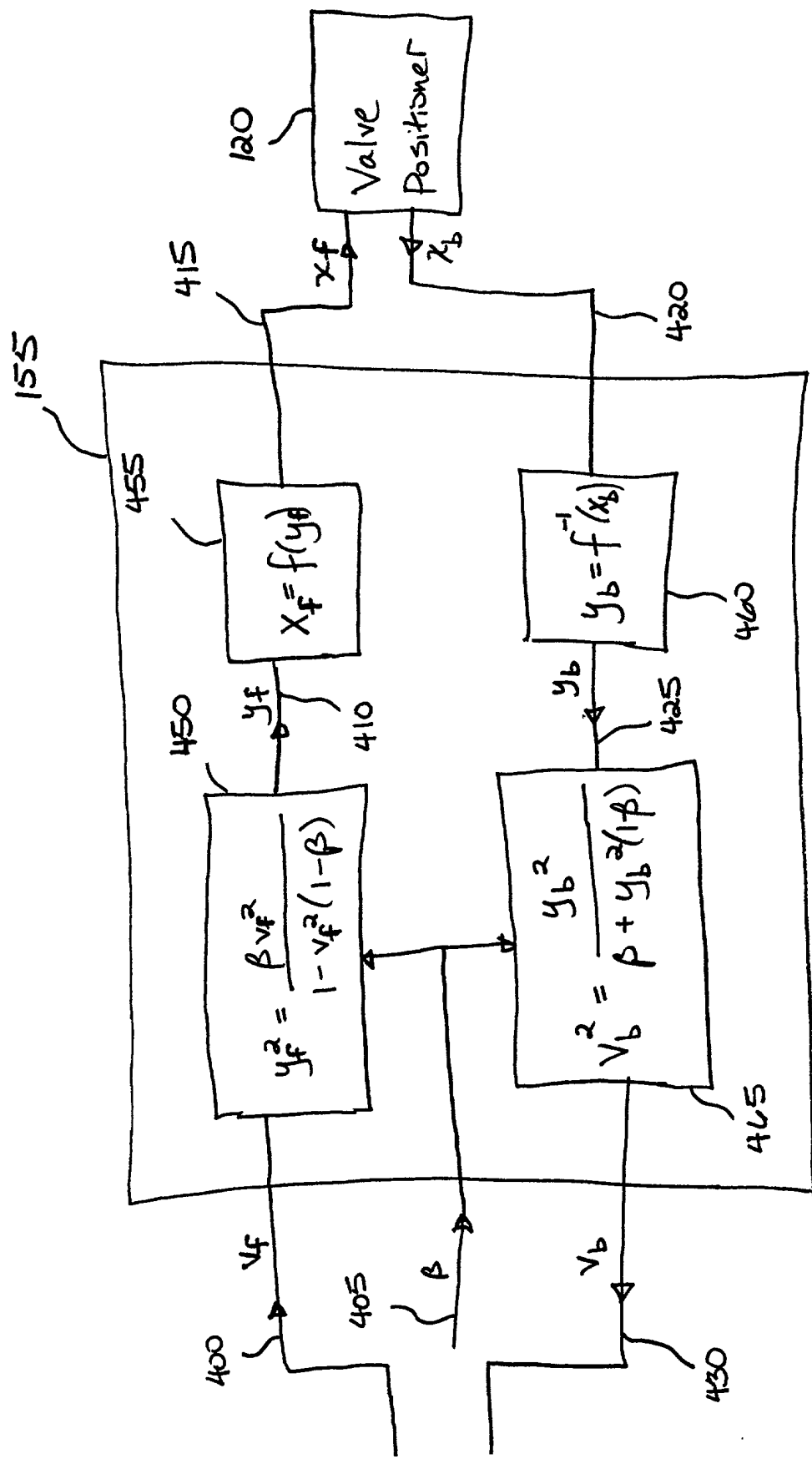
Fig. 4

F(mass flow rate)
determined by:

⊙ Isothermal gas flow, theoretical 510
── Shapiro, experimental 505

500

$\frac{P_2}{P_1}$

$\frac{F}{\text{Isentropic flow rate}}$

Fig. 5

$$v = \sqrt{\frac{y^2}{\beta + y^2(1-\beta)}}$$

flow rate, v

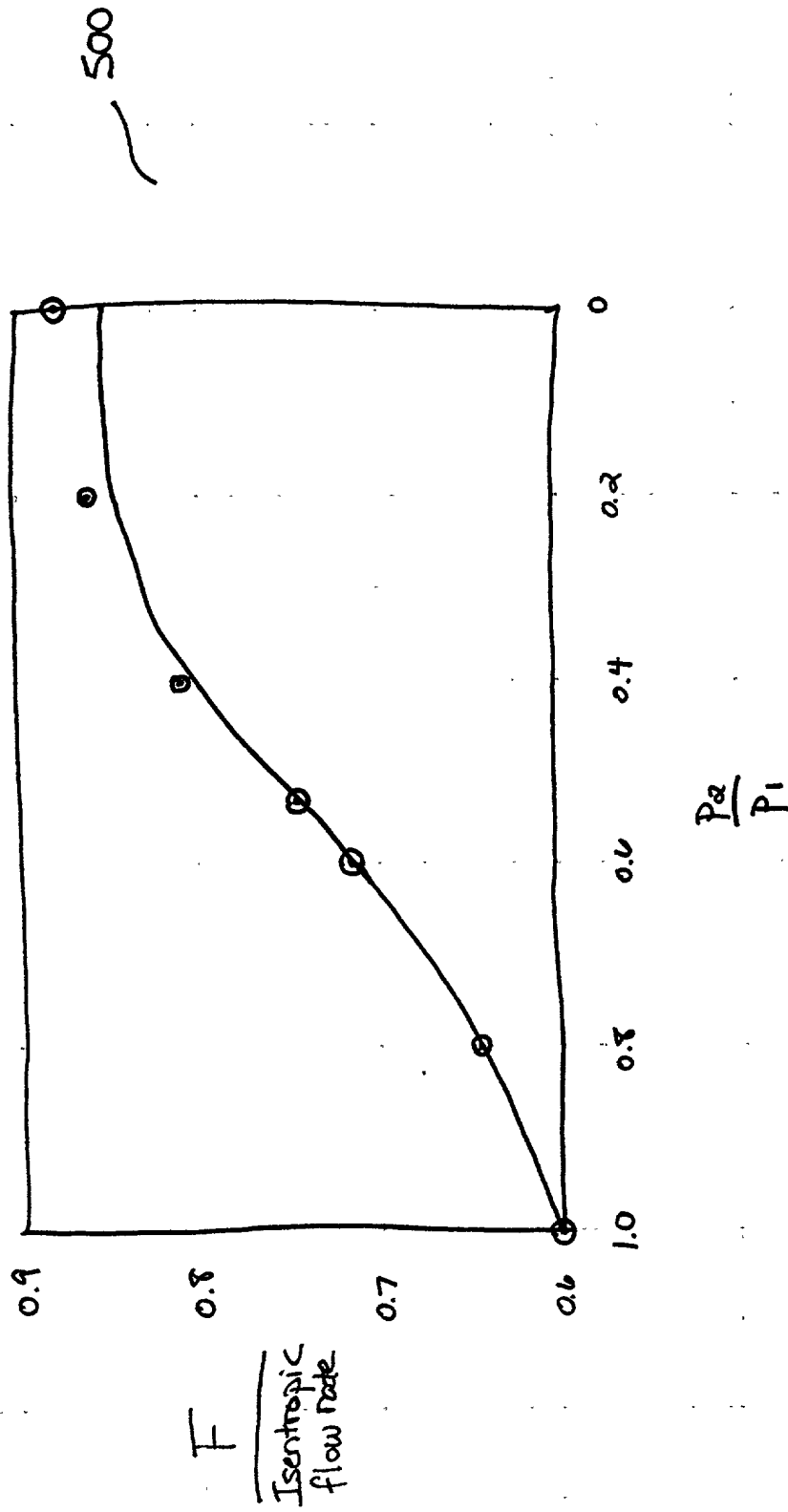flow area, y

~ 600

~ 610

$\beta = 1$
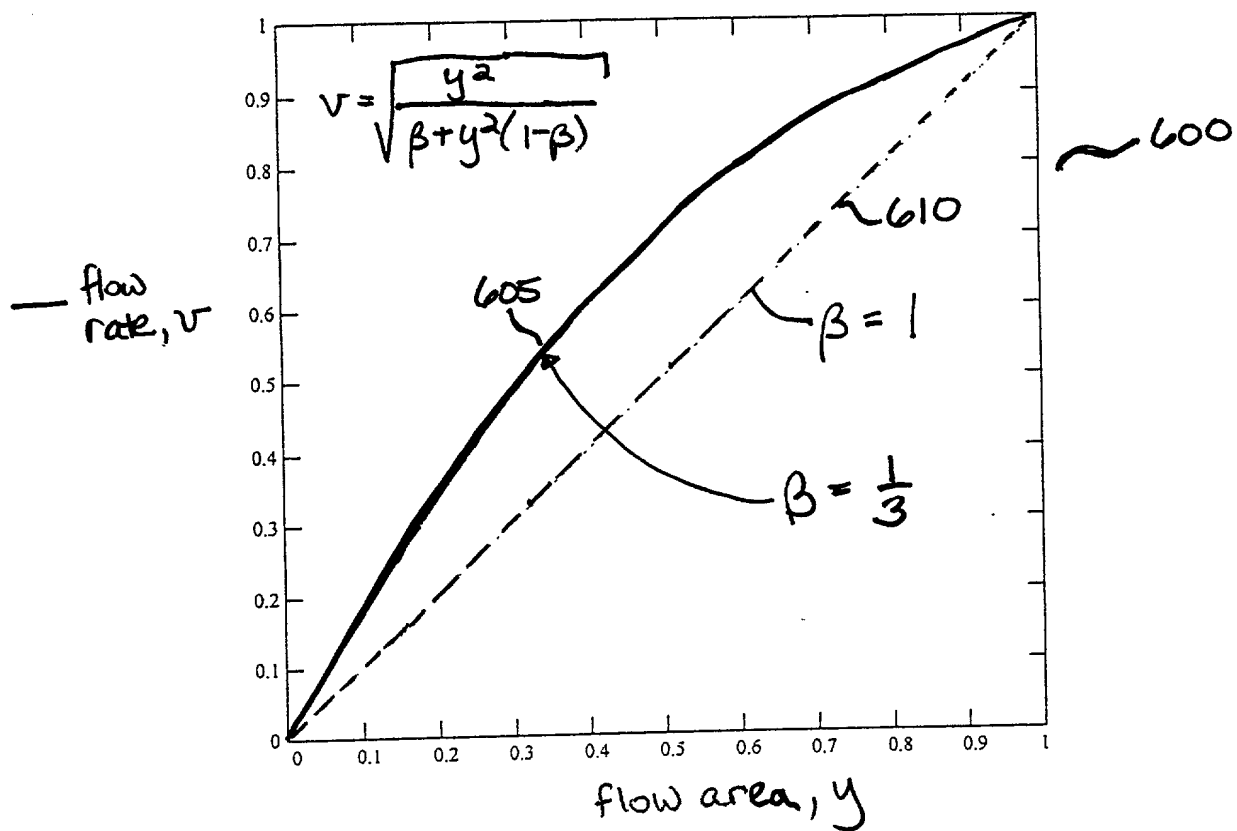
605

$\beta = \frac{1}{3}$

Fig. 6

COMBINED DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled <u>INTELLIGENT VALVE FLOW LINEARIZATION</u>, the specification of which

■ is attached hereto.

☐ was filed on _____ as Application Serial No. and was amended on _____.

☐ was described and claimed in PCT International Application No. filed on _____ and as amended under PCT Article 19 on _____.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose all information I know to be material to patentability in accordance with Title 37, Code of Federal Regulations, §1.56.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patents issued thereon.

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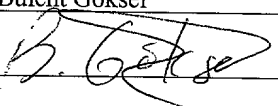
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